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Exploiting a GSM Network for Precise Payload Delivery

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This paper introduces the novel concept of using a GSM network for command of and communications with multiple aerial delivery systems. The research prototype of such a system, Snowflake-N, allows communicating with other network clients via a commercial Blackberry Curve 8310 handheld over a Bluetooth connection. A new architecture allows reassigning targets and sending other relevant commands (via web interface, by voice, data, or text messages) to an onboard autopilot, which is within a network reach, from any place in the world. Similarly, a current position of the descending system and target assignment can be viewed from any computer connected to the Internet worldwide using a standard Google Earth viewer. The networking capability also allows uplinking the latest weather data measured by a portable target weather station, being a part of a network as well, and therefore drastically improving an accuracy of a payload delivery. The paper extends the previous work by the authors and introduces the current state of the Snowflake-N development. It presents a C^2 concept for the aerial delivery systems, talks about communication protocols, presents the hardware set-up, components and results of recent drops. The paper ends with conclusions and recommendations for further development.

Abbreviations

ADS	=	Aerial Delivery System
AGL	=	Above Ground Level
AT&T	=	American Telephone & Telegraph
CEP	=	Circular Error Probable
EDGE	=	Enhanced Data Rates for GSM Evolution
FA	=	Final Approach
GNC	=	Guidance, Navigation and Control
GPRS	=	General Packet Radio Service
GSM	=	Global System for Mobile communications, originally from Groupe Spécial Mobile
JCTD	=	Joint Capability Demonstration
JMDSE	=	Joint Medical Distance Support and Evacuation
MSL	=	Mean Sea Level
NPS	=	Naval Postgraduate School, Monterey, CA
RF	=	Radio Frequency
SA	=	Situational Awareness
SIM	=	Subscriber Identity Module
TNT	=	Tactical Network Topology (experimentation series conducting quarterly at Camp Roberts, CA)
UAV	=	Unmanned Air Vehicle
UMTS	=	Universal Mobile Telecommunications System

I. Introduction

THE prototype of a miniature (3 lbs) air delivery system, Snowflake, was first demonstrated at Camp Roberts, CA in May of 2008 during TNT 08-03 experiments. Later in 2008 many drops of this system with an updated

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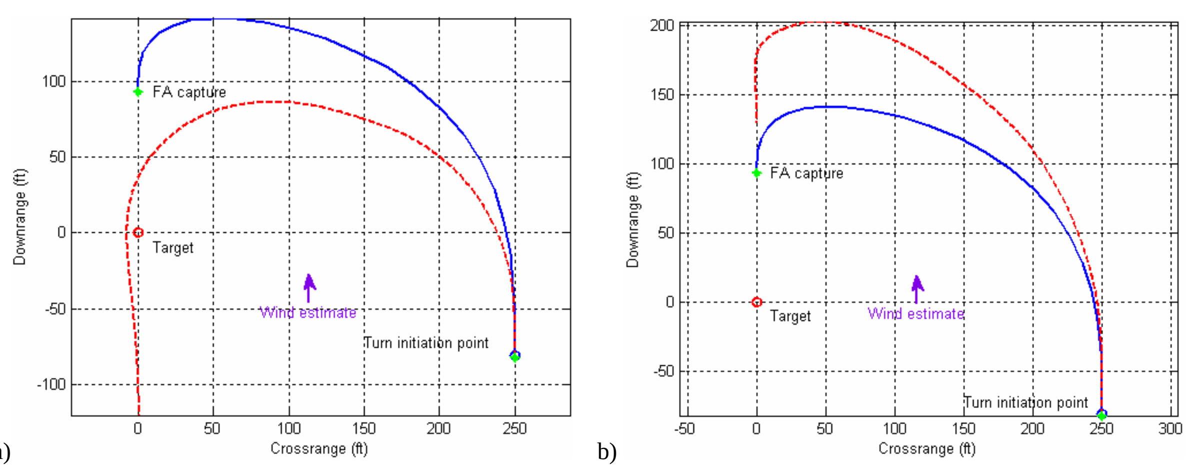
control algorithm took place at the U.S. Army Yuma Proving Ground in Yuma, AZ. These previous drops at Camp Roberts and Yuma Proving Ground demonstrated a CEP accuracy of 50m and 35m, respectively.[1] The Snowflake ADS employs quite an advanced control algorithm based on tracking an inertial trajectory produced on-line and dependant on estimated winds.[2] This trajectory allows guiding and landing Snowflake ADS into the winds. Being a research prototype, Snowflake does not use a flare capability, but if it did the CEP accuracy could easily be halved down to 15…20m. The authors' belief is that it is about the best accuracy that can be achieved for this type of systems without additional measures taking care of unknown winds during the last portion of the guided descend and constantly updating the trajectory based on these winds. It should be mentioned that the Implementation Directive for JMDSE / JCTD establishes the accuracy requirement for micro light weight systems (10…150 lbs) at the level of 50m (for comparison, for ultra light systems of 250…700lbs the accuracy requirement is degraded up to 150m CEP). Obviously, the achieved accuracy for Snowflake ADS meets the requirements to such systems already.

However, the intention of the NPS-UAH team is to drive the accuracy of the Snowflake prototype even further down to about 10…15m CEP. This can be achieved by: a) better knowing the current ground winds, and b) implementing an optimal terminal guidance algorithm. This latter algorithm has already been introduced in Ref.2, but its further modification should involve varying winds profile. Knowing the current ground winds can be achieved by measuring them and communicating up to the descending ADS. That brings us to an idea of networking. Although the authors do have an experience with networking UAVs,[3] this time instead of relying on the local network established using mesh cards, the authors explore an existing GSM network allowing a global reach capability.

The paper is organized as follows. Section II discusses modification of the existing control algorithm to account for growing errors (due to unknown winds) and therefore correcting guidance laws in a timely manner. It also suggests other modifications of the existing algorithms that would benefit in case the ground winds are known. Next, Section III introduces the GSM network and a developed concept of the networking Snowflake, Snowflake-N. It provides details on the overall architecture, including multiple Snowflake-N systems, target weather stations and TNT clients, along with addressing several interface issues. Finally, the results of some preliminary tests exploiting Snowflake-N networking capabilities are presented and discussed in Section IV (the testing of modified control algorithms is scheduled for mid May). The paper ends with conclusions.

II. Adaptive Terminal Guidance

The control algorithm addressed and fully disclosed in Ref.2 allows calculation of an optimal terminal turn trajectory bringing Snowflake from its current position down to the final approach intercept point (top of the final glide to the target). It was shown that the ability to recompute this trajectory every second or two takes care of minor wind disturbances. However, if the estimated winds are quite different from the real ones, there is not much one could do. To this end, Fig.1 presents an example of when the optimal trajectory was computed based on a tail wind *W* of 10ft/s while real winds occurred to be 5ft/s different (weaker or stronger). This 50% error in wind estimate (change in wind magnitude below the last known even accurate estimate) results in either large overshoot (Fig.1a) or landing short (Fig.1b). The solid line depicts a suggested reference trajectory and the dashed line represents a result of a six-degree-of-freedom simulation of how Snowflake ADS would track this trajectory and further perform a final approach and land.



a) b)

Fig. 1 Optimal guidance with constant unaccounted 5ft/s winds: "extra" head wind (a) and "extra" tail wind (b).

The capability to change final conditions during optimization allows mitigating the effect of the changing winds. Figure 2 shows that a simple update with the same final point does not help (compare it with Fig.1). Yet, if during an update we move the location of the FA capture point accordingly, depending on the error between the old reference trajectory and a current position at the time of the update, we may be able to decrease the overall touchdown error. For instance, while the touchdown error in Fig.2a is 120ft (overshot), a single update with moving the final point further downwind allows decreasing this error down to 75.2ft (Fig.3a). With four updates (Fig.3b) this error reduces to 33ft, only one quarter of the original one. Although the direct method used in terminal guidance[2] allows for more updates, it was found that it would be impractical, since improvements in the FA capture require a build up in error. Otherwise, we could find ourselves trying to chase small zero-mean wind disturbances that can be effectively fought even without having the intended FA capture point moved.

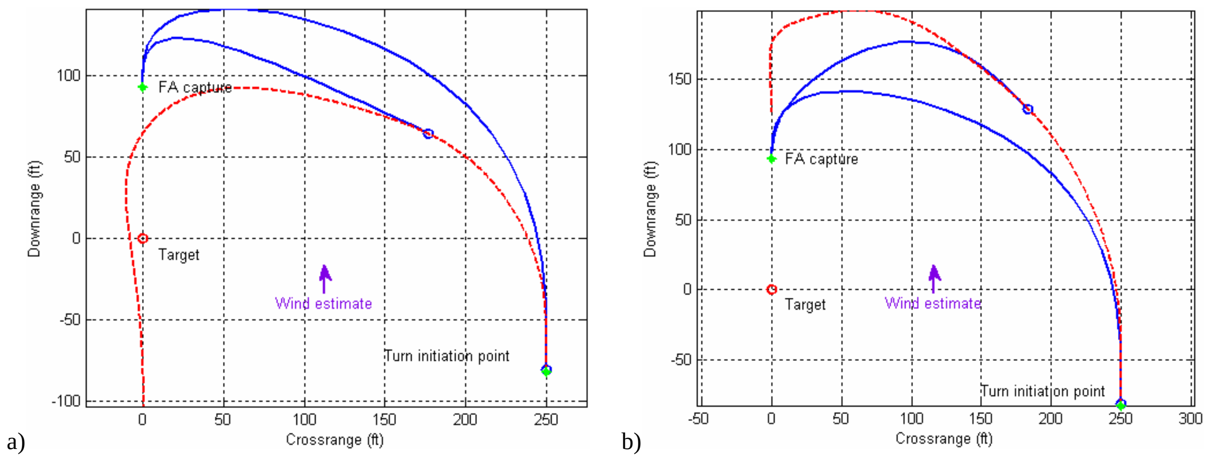


Fig. 2 Optimal guidance with a single update to account for unknown 5ft/s winds: "extra" head wind (a) and "extra" tail wind (b).

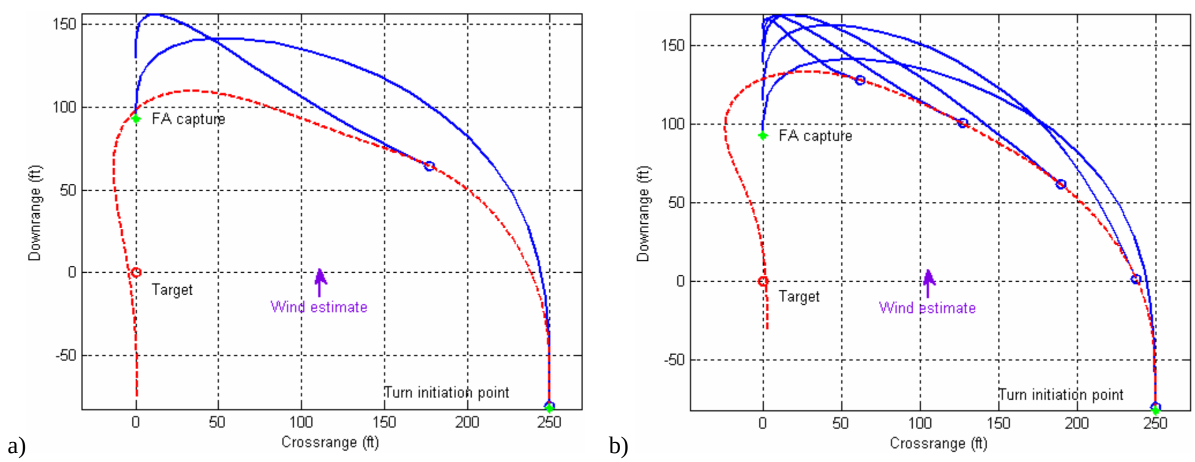


Fig. 3 Optimal guidance with unaccounted head wind of 5ft/s and adaptive terminal conditions for a single-update (a) and four updates (b).

Now, let us assume, that at the moment the parafoil starts its final turn not only we have a wind estimate W, but we also know the x-component of the ground wind W_G. Hence, instead of using a constant wind profile, we might try to use an altitude-variant, say linear profile. Additionally assuming a constant descent rate we arrive to the following time-variant wind profile:

$$W(t) = W_G + \frac{W - W_G}{t_0 - t_2}(t - t_2)\,, \tag{1}$$

where t_0 is the time corresponding to the beginning of the final 180°-turn and t_2 is the time of touchdown. With this wind profile Eq.(26) in Ref.2 changes to

$$D_{switch} - \frac{W + W_G}{2}(T_{turn} + T_{app}) - V_h^* T_{app} = 0\,, \tag{2}$$

Eq.(30) to

$$z_{start} = V_v^* \frac{L + V_h^*(T_{turn} + 2T_{app}^{des})}{W - V_h^*} + V_v^* \frac{1}{2} \frac{(W_G - W)(T_{turn} + T_{app}^{des})}{W - V_h^*}\,, \tag{3}$$

and Eq.(33) to

$$\hat{D}_{switch} = -\frac{\hat{z}(2\hat{V}_h^{*2} + \hat{V}_h^*(\hat{W}_G - \hat{W}) - \hat{W}(\hat{W}_G + \hat{W})) + 2\hat{V}_h^*\hat{V}_v^* T_{turn}(\hat{V}_h^* - \hat{W}) + \hat{x}\hat{V}_v^*(2\hat{V}_h^* + \hat{W}_G + \hat{W})}{\hat{V}_v^*(4\hat{V}_h^* + \hat{W}_G - \hat{W})}\,. \tag{4}$$

These formulas are now to be used for a constant turn rate guidance. With the default value of $\hat{W}_G = \hat{W}$ Eqs.(2)-(4) converge to Eqs.(26),(30),(32) in Ref.2. However, if the *x*-component of a ground wind W_G is known (measured and uplinked to the ADS), then the altitude of exiting the loiter area is computed according to Eq.(3), and distance $\hat{D}_{switch}$ triggering the beginning of the turn maneuver – according to Eq.(4).

For the optimal guidance algorithm accounting for a linearly changing wind profile (1) is even easier. In this latter case (if W_G is known), we start from $W_1 = \hat{W}$. Then, we modify Eq.(53) in Ref.2 as

$$\Delta t_{j-1} = \sqrt{\frac{(x_j - x_{j-1})^2 + (y_j - y_{j-1})^2}{V_h^{*2} + W_{j-1}^2 - 2V_h^* W_{j-1}\cos\psi_{j-1}}}\,, \tag{5}$$

followed by

$$W_j = W_{j-1} + \frac{\hat{W} - \hat{W}_G}{T_{app}^{des} + T_{turn}} \Delta t_{j-1}\,. \tag{6}$$

Then we proceed with the only change in Eq.(55) of Ref.2 as follows:

$$\psi_j = \tan^{-1} \frac{\lambda_j y_j'}{\lambda_j x_j' + W_j}\,. \tag{7}$$

Finally, if the entire wind profile $W(h)$ is measured by one ADS and then communicated up to the following descending ADS, the optimal heading profile (7) can easily adopt it as well.

Now let us address a question on how to measure and communicate these winds up to descending ADS.

III. Exploring Network Capabilities

The new addition to the Snowflake ADS allows exploiting the existing GSM network rather than having wireless mesh cards added to the system components. Originally developed for the single purpose of communicating with target weather stations to enable better touchdown accuracy of the Snowflake ADS, the developed architecture allows doing much more and some of these new capabilities, e.g. dynamic target reassignment were demonstrated during the TNT 09-02 experiments. In what follows the GSM network is being introduced first, followed by the detailed description of the latest additions to the Snowflake ADS architecture.

A. GSM Network

Global System for Mobile communications, originally from Groupe Spécial Mobile, is the most popular standard for mobile network in the world. Its promoter, the GSM Association, estimates that 80% of the global mobile market uses this standard.[4] As seen from Fig.4 the GSM network is used by over 3 billion people across more than 212 countries and territories.[5,6] The GSM network differs from its predecessors in that both signaling and speech channels are digital, and thus is considered a second generation (2G) mobile phone system. This also means that data communication is easy to build into the system. Specifically, Release '97 of the standard added packet data capabilities, by means of GPRS. Release '99 introduced higher speed data transmission using EDGE. Another key feature of GSM is the SIM, commonly known as a SIM card. The SIM is a detachable smart card containing the user's subscription information and phone book. This allows the user to retain his or her information after switching handsets. Alternatively, the user can also change operators while retaining the handset simply by changing the SIM.

The GSM is a cellular network, which means that mobile phones connect to it by searching for cells in the immediate vicinity. There are five different cell sizes in the GSM network—macro, micro, pico, femto and umbrella cells. The coverage area of each cell varies according to the implementation environment. Macro cells can be regarded as cells where the base station antenna is installed on a mast or a building above average roof top level. Micro cells are cells whose antenna height is under average roof top level; they are typically used in urban areas. Picocells are small cells whose coverage diameter is a few dozen meters; they are mainly used indoors. Femtocells are cells designed for use in residential or small business environments and connect to the service provider's network via a broadband internet connection. Umbrella cells are used to cover shadowed regions of smaller cells and fill in gaps in coverage between those cells.

Fig. 4 The GSM network world coverage as of 2008.

Macro and micro cell horizontal radii vary depending on antenna height, antenna gain and propagation conditions from a couple of hundred meters to several tens of km. The longest distance the GSM specification supports in practical use is 22mi. There are also several implementations of the concept of an extended cell, where the cell radius could be double or even more, depending on the antenna system, the type of terrain and the timing advance. Also, new cells can be easily created using an Internet connection (to be addressed in Section IIIB).

The GSM network operate in a number of different frequency ranges (separated into GSM frequency ranges for 2G and UMTS frequency bands for 3G).[7] The 2G GSM network operates in the 900MHz or 1800MHz bands. Some countries (including Canada and the United States) use the 850MHz and 1900MHz bands because the 900MHz and 1800MHz frequency bands were already allocated. The 3G GSM network in Europe operates in the 2100MHz frequency band. The rarer 400MHz and 450MHz frequency bands are assigned in some countries where these frequencies were previously used for first-generation systems. The GSM-900 uses 890…915MHz to send information from the mobile station to the base station (uplink) and 935–960 MHz for the other direction (downlink), providing 124 RF channels (channel numbers 1 to 124) spaced at 200kHz.

The network behind the GSM seen by the customer is large and complicated in order to provide all of the services which are required. It is divided into a number of sections as shown in Fig.5:

- the Base Station Subsystem (the base stations and their controllers);
- the Network and Switching Subsystem (the part of the network most similar to a fixed network);
- the GPRS Core Network (the optional part which allows packet based Internet connections).

All of the elements in the system combine to produce many GSM services such as voice calls and SMS. In turn, this enables another valuable feature - voice control. In many cases, even the most experienced operators have little to no opportunity to look away from the task at hand in order to concentrate on a computer screen. Unlike a visually-rich common operational picture tool, voice communication interferes substantially less with an operator's ability to carry out a concurrent task. This approach may be one of the few feasible solutions for tasking unmanned systems and getting response messages while keeping hands and eyes free for more immediate tasks.

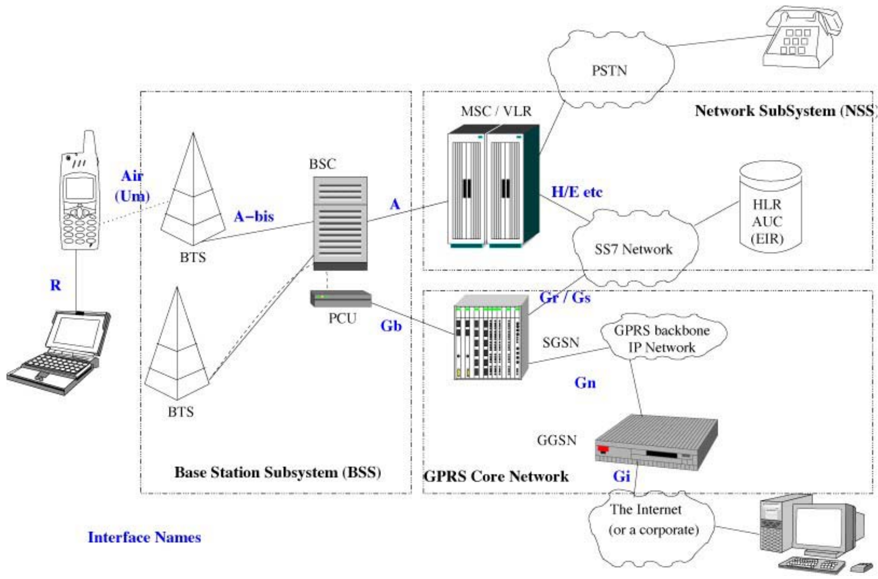


Fig. 5 The structure of a GSM network.

The last decade's advances in VoiceXML, CCXML, CallXML, and other voice-based computer control techniques provide a unique background for this new research dimension - voice control of computer infrastructure, platforms, and sensors. Voice commands may be delivered to the platform for execution either over a wide area network connection, like the Internet, or from within the local cellular network infrastructure. The use of a combination of both may be very beneficial to extending this capability to the edge, providing any network- or cellular-equipped forward operator a means to directly interact with unmanned systems, not only by clicking and viewing, but by speaking and hearing.

The voice control solution represents a good example of an alternative approach to sharing situational awareness information between human and machine across a network. In an operating environment augmented by unmanned systems, this brings us significantly closer to the long-anticipated goal of seamlessly using natural language with robots. This so-called Voice-on-Target approach provides a platform with the ability to exchange data through synthesized voice. As a result, operators can literally hear unmanned systems "talking" back to them, providing the current status of a task via voice report. This in turn enables operators to begin "sensing" more intuitively through unmanned systems, thus improving their cognition and situational understanding.

Let us see now what the components of Snowflake-N version are and how they fit into the GSM cellular network architecture.

B. Networked Snowflake Concept

The overall communication block diagram of Snowflake-N is shown in Fig.6. As shown in this figure the Snowflake payload now includes a standard Blackberry 8310 cell phone, which communicates with the autopilot via Parani-ESD200 Bluetooth to serial module. This allows sending and receiving packages of data via the AT&T GSM network / Internet to the SA server located at NPS. The ground stations (Fig.7) also have a Blackberry / Bluetooth module bundle allowing them to be clients of the network as well. Lastly, the Operator can interfere at any moment via computer (Internet or TNT network), via GSM handheld (Fig.8), or via voice portal to change any mission parameters.

Several target weather stations (Fig.7) were built in house and represent a combination of three parts: Kestrel 4000 weather station, measuring winds and barometric pressure, serial to Bluetooth interface, and Blackberry 8310 cell phone. The portable Kestrel 4000 weather station's dimensions are 5"x 1.8" x 1.1" and it only weights 3.6oz. In terms of accuracy, Kestrel 4000 is capable of measuring wind's direction within 5º, speed – within 0.1kts and atmospheric pressure – within 0.1psi. Theoretically, it is only capable of automatically storing measurements and then uploading them through a serial or USB port. However, the authors managed sending data as a serial stream through a Bluetooth module, therefore interfacing the serial stream with a standard Blackberry 8310 cell phone carrying a AT&T SIM card.

An operator's Blackberry handheld interface is shown in Fig.8. In its current configuration an operator can assign targets by voice or manually using a cell phone or emulate using a cell phone and assign the targets via Internet (using the same interface).

The structure of a communication packet being sent from Snowflake to the ground station is presented in Fig.9, while the Snowflake-SA server two-way data format is described in detail below.

The SA server message to Snowflake-N (Table 1) contains three lines with data needed to compute the descent trajectory:

- Waypoint: WP,TargetLat,TargetLon<CR>
- Target Weather Condition: TWC,WindSpeed,WindDirection,Barometer<CR>
- Release Command: RL,Release,Delay,MinAlt<CR>

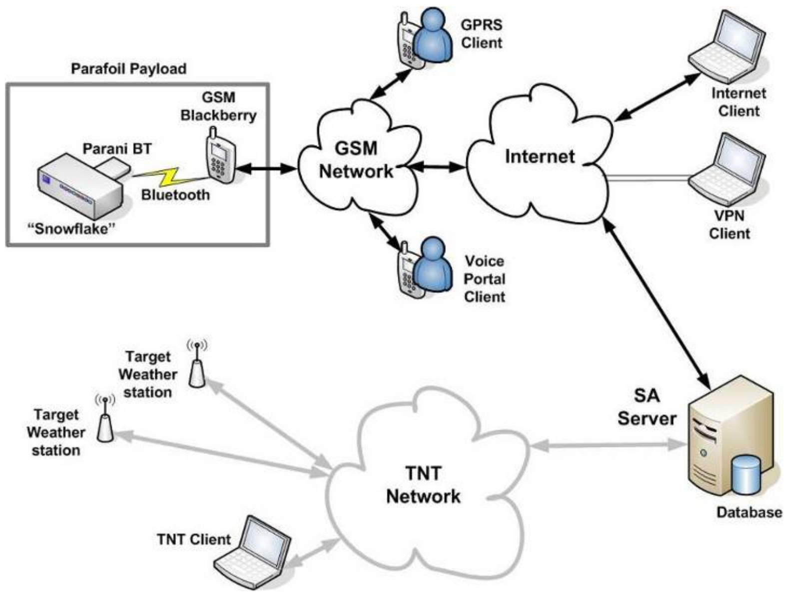


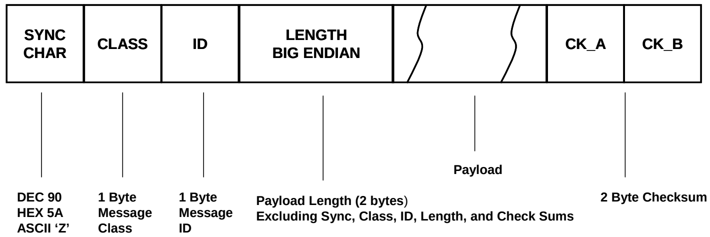
Fig. 6 Communication block diagram.

Fig. 7. The wireless target weather station posting its data over Blackberry handheld (on the back).

Fig. 8 Blackberry Curve 8310 handheld with Snowflake control interface.

Snowflake responds to the SA server with a message containing the following data (Table 2): DAT, Time, Latitude, Longitude, Altitude, Fix, Phase, Update, TargetID, TargetLat, TargetLon, TargetPre, TargetWS, TargetWD, UpdateTime, TargetAssignmentStatus <CR>. For example,

DAT,23:23:03,34719151,-86638521,1640,2,0,1,23,35123450,-121543210,13.001,3.5,153.0,23:16:44,1<CR>



- Every Message starts with 1 Byte: 0x5A;
- A 1 Byte Class Field follows. The Class defines the basic subset of the message;
- A 1 Byte ID Field defines the message that is to follow;
- A 2 Byte Length Field is following. Length is defined as being the length of the payload, only. It does not include Sync Chars, Length Field, Class, ID or CRC fields. The number format of the length field is an unsigned 16-Bit integer in Big Endian Format;
- The Payload is a variable length field;
- CK_A and CK_B is a 16 Bit checksum

Fig. 9 Structure of a Snowflake-N to ground station communication packet.

Table 1. The SA server - Snowflake message.

Name	ASCII String Format	ASCII String Example	Units	Description
			Line 1	
TargetID	Int8	23	-	1-99, 0 means no Target ID assigned
TargetLat	signed int32	34010345	deg * 10^6	Target latitude
TargetLon	signed int32	-121567001	deg * 10^6	Target Longitude
			Line 2	
WindSpeed	Decimal	3.3	ft/s	Wind Speed (>0)
Direction	Decimal	270.0	Deg	Direction wind is coming from
TargetPre	Decimal	15.123	psi	Target Barometric Pressure
			Line 3	
Release	int1	0	-	1 = Release Snowflake, 0 = Don't
Delay	unsigned int16	5	seconds	Canopy Deployment Delay After Release
MinAlt	unsigned int16	2500	ft	Minimum Deployment Altitude Above Ground

Table 2. Snowflake - SA server message.

Name	ASCII String Format	ASCII String Example	Units	Description
Time	hh:mm:ss	07:22:33	-	UTC (GMT)
Latitude	signed int32	34010345	deg * 10^6	GPS latitude
Longitude	signed int32	-121567001	deg * 10^6	GPS Longitude
Altitude	unsigned int16	3320	ft	GPS Height above mean sea level
Fix	int8	3	-	0=No Fix, 2 = 2D, 3 = 3D
Phase	int8	5	-	Guidance Stage 0-6
Update	int1	0	-	1/0 GPS Target Updated Allowed/Not
TargetID	Int8	23	-	1-99, 0 means no Target ID assigned
TargetLat	signed int32	34010345	deg * 10^6	Target latitude
TargetLon	signed int32	-121567001	deg * 10^6	Target Longitude
TargetPre	decimal	15.123	psi	Target Barometric Pressure
TargetWS	decimal	3.3	ft/s	Wind Speed (>0)
TargetWD	decimal	270.0	Deg	Direction wind is coming from
UpdateTime	hh:mm:ss	07:22:33	-	UTC (GMT)
TargetAssignmentStatus	int1	1	-	0 - cancel target; 1 - target assigned; 2 - target is out of range, so unit is switched back to the previously assigned target

These data can be called up by clicking on the Snowflake symbol at the Google Earth – based screen of the SA server anywhere in the world as shown in Fig.10.

Fig. 10 Example of Snowflake-N data being displayed within the Google Earth environment.

The Snowflake-N autopilot logic in determining if an assigned target is accepted is based on a comparison of the maximum distance the parafoil can possibly glide from the current altitude *H*: $D_{\max} = \hat{H}\hat{V}_h^*\hat{V}_v^{*-1}$ (where $\hat{H}$ is an estimate of a current altitude, $\hat{V}_h^*$ and $\hat{V}_v^*$ are the estimates of horizontal and vertical components of the total ground speed vector) and the distance from a new target D_T. If

$$D_T + \Delta D < \hat{H}\hat{V}_h^*\hat{V}_v^{*-1} \tag{8}$$

(ΔD is some safety buffer), then the new target is accepted. Otherwise the parafoil continues to glide to the last accepted target (or to a default target in the case there was no communication between the ground weather station and Snowflake-N). In addition to that, an acceptance of a new target is blocked if Snowflake-n is less than 500ft above the loiter area exit altitude.

IV. Preliminary Test Results

The goal of initial tests of Snowflake-N ADS during TNT 09-02 experiments at Camp Roberts, CA was to demonstrate the developed communication capability between Snowflake-N system(s) in the air, ground weather station(s) established by each of the multiple targets, and the command center. To this end, two different targets (Red and Blue) were established along with the default target (used in the case of lost communication). The location of these targets along with a suggested loiter area to manage Snowflake energy (altitude) is shown in Fig.11. Figure 12 shows a red target, marked with a (red) flag with the weather station attached to the tip of the pole. Figure 13 shows two ready to be deployed Snowflake-N ADSs with Futaba controllers behind them (allowing control over each system in case of emergency). The Snowflake ground station laptop allows monitoring a status of all systems.

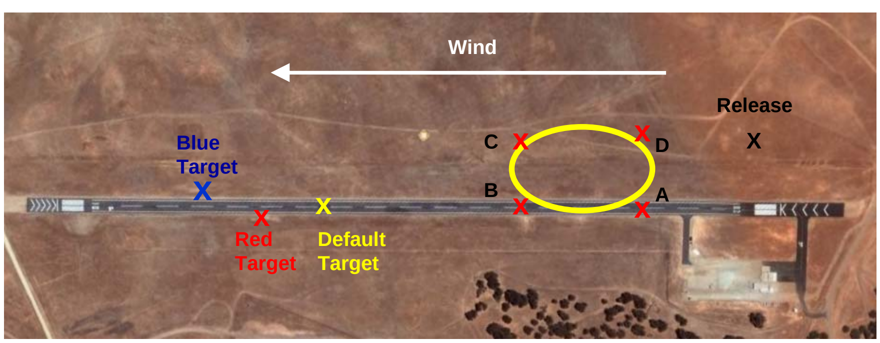


Fig. 11 Blue, Red and default targets.

Fig. 12 Red target with a miniature wireless weather station and Blackberry phone.

Fig. 13 Two armed Snowflakes, ready to be deployed.

Two armed systems are being loaded into the general aviation Cessna-172 aircraft as shown in Fig.14. The SA display at this moment shows two active targets (BBWS1 and BBWS2) and two active Snowflakes (SF1 and SF2) inside the cockpit of the aircraft ready to take off (Fig.15).

It should be noted that a GPS position coming out of Blackberry 8310 cell phone is only accurate within several meters. As any stationary GPS receiver, Blackberry-based weather station has a higher error probability, which causes calculation inaccuracy in positioning, as well as position drift as shown on Fig.16. To minimize this effect the averaging algorithm was applied on SA Server while collecting GPS data from weather stations.

Fig. 14 Loading two armed Snowflakes into the Cessna-172 airplane.

Figure 17a shows the situation when the operator (Fig.18) has assigned one of two targets to the descending system, shown connected with a straight line. Note, this is not a suggested trajectory but a line indication that that the Snowflake ADS has a target assigned to it. The operator can assign a new target at any time while Snowflake is airborne (later on the NPS-UAH team plans to land Snowflake-N onto a moving platform, so it is crucial to be able to transmit a new target position as often as possible).

Once the target is communicated to the descending Snowflake-N ADS, it develops an optimal trajectory to reach this target and starts following it. At some point the system is low enough, so it cannot accept any more changes in the target position and that is when Snowflake's marker on the SA display turns orange (Fig.17b).

Fig. 15 Two Snowflakes sitting inside Cessna-172 before take-off.

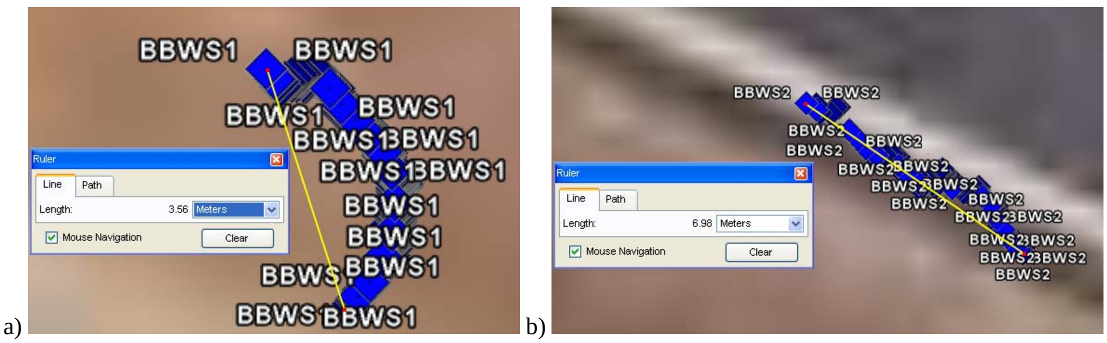


Fig. 16 Drifting of target weather station GPS position posted to SA.

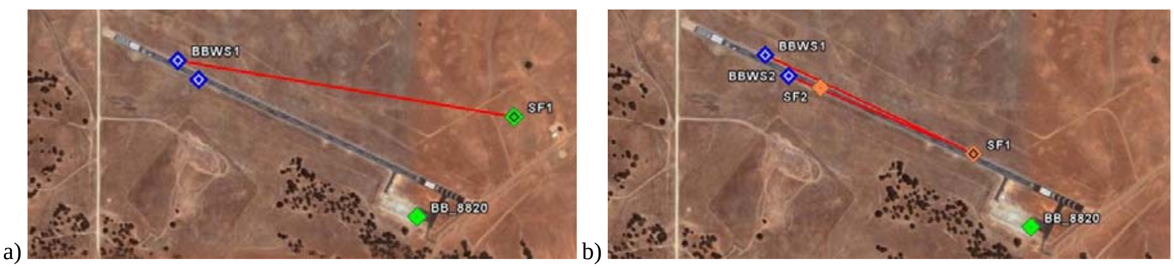


Fig. 17 Snapshots of the SA control screen.

Fig. 18 Reassigning targets from the operator's display (emulating the screen of a cell phone).

Figures 19 and 20 show the trajectories of four systems released sequentially during the experiment as recorded by autopilot. Figure 21 presents an example of parameters that are recorded during the drop. Figure 22 shows the trajectory as recorded by the SA server. Figure 23 shows the descent of one of the systems recorded by the digital camera. As seen, the first system was deployed too far from the target and never reached even the loiter area (Fig.19a). The second one however did better and landed within 23m from its target (Fig.19b). The third and fourth systems, deployed from the higher altitude both did well and landed within 28m and 25m from their targets, respectively (Figs.20a and b). Therefore, the achieved CEP accuracy for three systems is 25m. This is 30% less than that reported in Ref.1 (35m). This improvement can be attributed to two factors – better accuracy in current altitude estimate (by knowing current barometric altitude at the target location), and implementing an advanced guidance algorithm (1)-(4) based on the knowledge of current winds by the target.

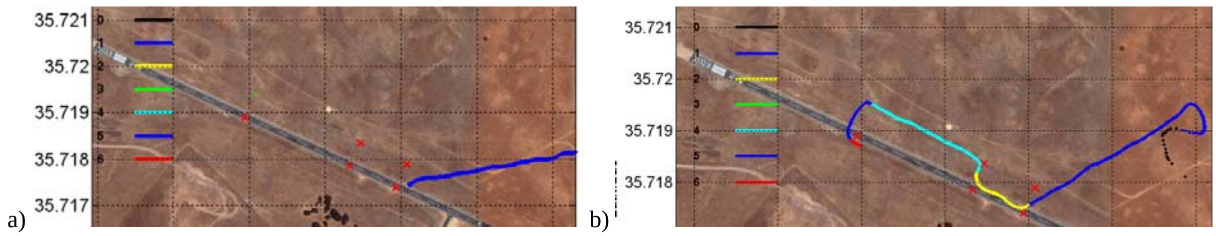


Fig. 19 Trajectories of the first two systems released from 2,000ft AGL.

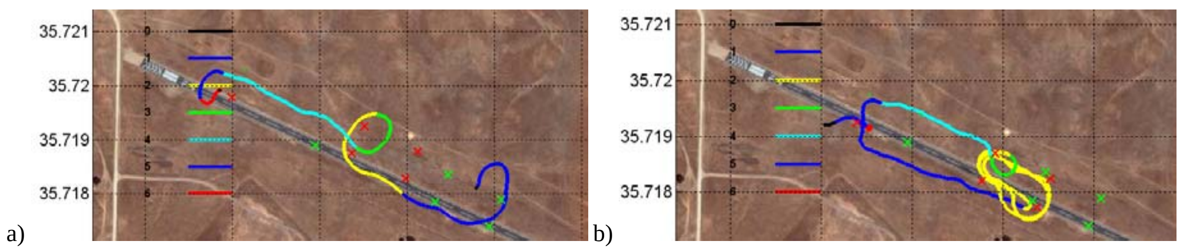


Fig. 20 Trajectories of the second two systems released from 4,000ft AGL.

For example, Fig.20 shows some of parameters of the drop presented in Fig.20a. Specifically, due to networking between the weather ground station and descending Snowflake-N the altitude estimation error happened to be of the order of 3m (Fig.21a). The target assignment negotiation was held down to about 1,000ft (at the lower altitude no target changes were accepted). The downwind component of the wind was estimated to be near zero (Fig.21c), but apparently it were cross winds that blew Snowflake South during the final 180º turn, so it had to recover during a final approach.

It turned out that due to a weak GSM signal in most of Camp Roberts, the SA server postings over the GSM network were not as reliable as expected (Fig.22). Despite of the fact that it did not affect the overall system's performance, more considerations should be given to this matter in the future. One of possible solutions for the areas of operation with poor AT&T cell phone coverage would be migration to Verizon network platform. However, the best solution would be a usage of a tactical cellular network infrastructure as shown in the bottom part of Fig.6. This infrastructure may be provided by deploying a cellular base station to the area of operation for significant improvement of local GSM coverage. Tactical cellular network may supply either autonomous operation within one local GSM cell, or original network infrastructure (Fig.6), where tactical cellular base station is connected directly to the TNT network. In other words, in case of poor coverage, the commercial GSM network cloud in Fig.6 may be substituted by a cloud of local tactical GSM network (macro or micro cells). Blackberry SIM cards replacement and local network settings adjustment will be required in this case, and that will be a continuation of a Snowflake-N development.

V. Conclusions and Further Development

The concept of controlling Snowflake ADS over the GSM network was proven to be a viable option worth further development. Specifically, further investigation is needed to assess the effect of a poor GSM signal on overall systems performance and a capability to deploy a local tactical extension of the GSM network in the areas with a limited or no GSM coverage. More drops are expected in preparation to TNT 09-03 experimentation scheduled for May of 2008.

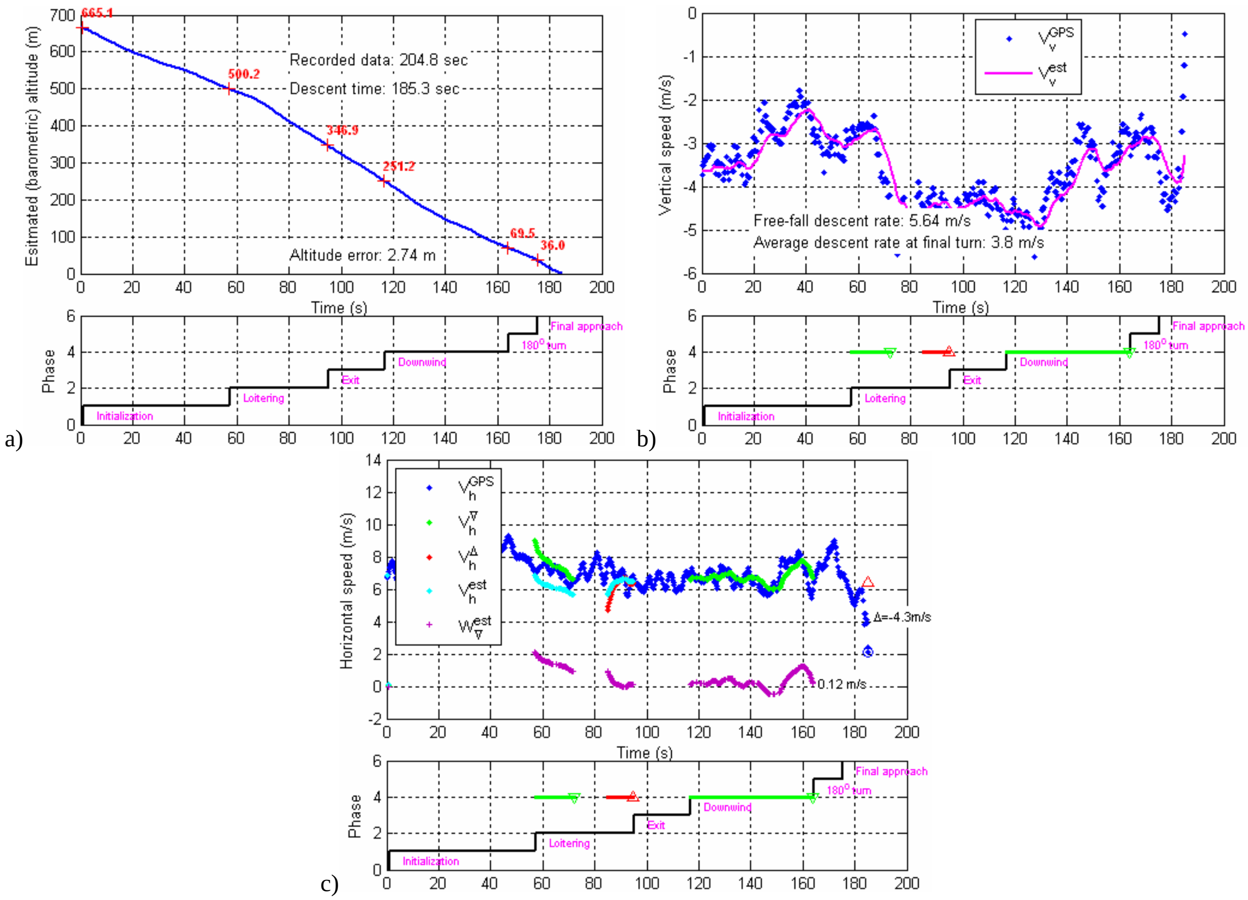


Fig. 21 Altitude (a), vertical (b) and horizontal (c) speed profiles for the drop shown in Fig.20a.

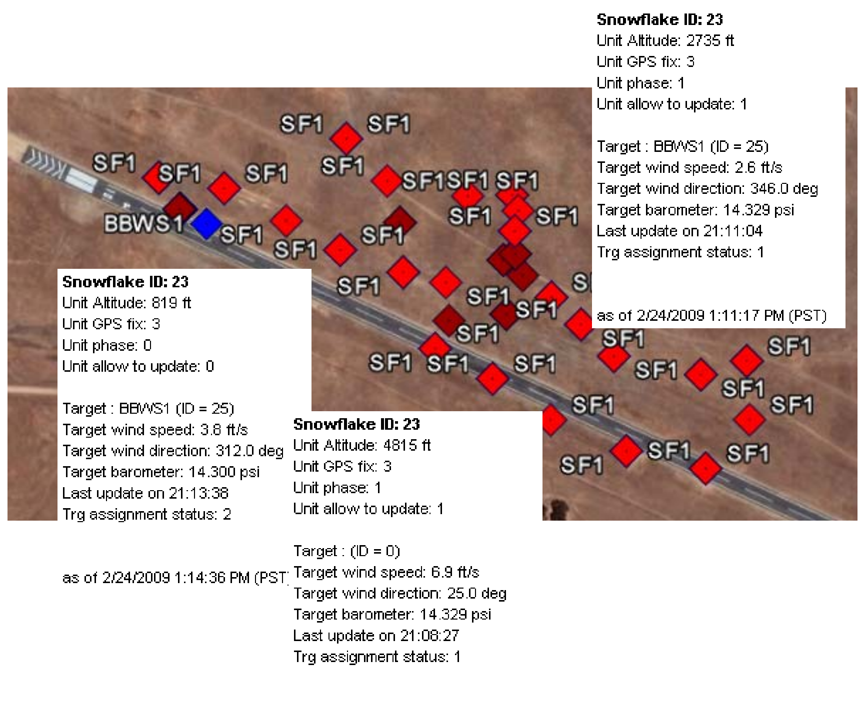


Fig. 22 Trajectories of the second pair of Snowflake-N ADS released from 4,000ft AGL.

Fig. 23 Snowflake in the air descending from 4,000ft AGL.

Acknowledgments

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